ARE LEAN MANUFACTURING EFFORTS REFLECTED IN CORPORATE FINANCES?

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Abstract
There are direct relationships between work in process inventory, cycle time, and throughput for most manufacturing processes. Companies that focus on lean manufacturing principles are aware of these relationships, and strive to minimize work in process and cycle times in order to maximize their manufacturing efficiencies. A study has been conducted to determine whether some of these relationships can be seen at the corporate level. Many companies have recently begun reporting more detailed information regarding their inventory figures, and include work in process data in their annual reports. Several industries are investigated here to determine whether corporate results reflect their concern – or lack of concern - regarding manufacturing efficiencies. Of particular interest are the automotive, the consumer goods, and the pharmaceutical industries.

Key Words
Lean Manufacturing, Factory Physics, Financial Analysis

Introduction
Lean manufacturing concepts have been widely publicized since the 1980's, and many industries have embraced these concepts. Toyota Motor Corporation is generally credited with creating the concept of lean manufacturing. The "Toyota Production System" evolved out of need; during the 1970's the company simply did not have the resources to spend on excess inventory. The system was developed to eliminate waste wherever it was found, including scrap, inventories, and off-quality material. Over time, Toyota began eliminating wasted time as well as wasted materials (Ohno, 1988).

The objective of lean manufacturing is to streamline the flow of materials though the production process (Standard & Davis, 1999). While many of the techniques have been applied across the automobile industry, not all industries have embraced the ideas of lean manufacturing. Experience has shown that many of the concepts have been applied in the consumer goods industry, but these ideas are not understood in the pharmaceutical industry. This observation has also been documented in the literature (Elliott, 2006).

Factory Physics® is a description of the underlying behavior of manufacturing systems; a 'science' of manufacturing (Hopp & Spearman, 2001). The tools of Factory Physics allow a person to identify areas of improvement in serial production lines. This can be applied to not only metal fabrication, but also to the chemical process industries. Internal benchmarking can be used to identify how well a manufacturing operation is functioning compared to its own ideal potential. Internal benchmarking can also be used as a tracking tool to gauge improvements made to an operation.

These tools have been successfully applied to individual operations in a wide assortment of companies and industries. The tools are meant to be applied to individual production lines, to measure and improve the efficiency of manufacturing systems. The tools are used at a micro level.

Can these tools be applied to the corporation as a whole? Do the micro-level tools also work at a macro level? Can a company's average efficiency be determined and compared to others? This paper is a work in process to determine whether some of the lean manufacturing relationships can be seen at the corporate level, using publicly available financial accounting data.

Manufacturing Efficiency
Various industries have taken different approaches to the subject of manufacturing efficiency. Some, such as the automobile industry, have a high cost of goods relative to their income. Some, such as pharmaceuticals, have a relatively low cost of goods. Manufacturing is a key cost center for automobiles, but is not a focus for pharmaceuticals. Manufacturing efficiency is very important to the profitability of the auto industry, but is almost a foreign concept to the prescription drug business.

Ohno (1988) described seven types of waste, saying that true efficiency improvement comes when we produce no waste and bring the percentage of work to 100 percent. The seven types of waste were identified as:

1. Overproduction
2. Waiting; waste of time on hand
3. Transportation; moving materials around the plant
4. Over processing; effort to deliver features that have no value
5. Inventory
6. Motion; movement of people, tooling, and equipment that does not add value

7. Defective product.

Sometimes an 8th item is added to the list (Alukal, 2003):

8. People; not fully using a person's mental and creative skills and experiences.

Eliminating these wastes can significantly improve operating efficiency.

In recent years, industry has significantly reduced manufacturing costs by a variety of methods. One of the primary methods has been the reduction of inventory, resulting in a decrease in the amount of capital that is tied up in the manufacturing process (Riggs, 2004).

Work in Process, Inventory, and Cycle Time. Studies of serial production systems have been around since the industrial revolution, including Adam Smith's famous description of the pin factory (1789). In the 1980s, various mathematical modeling studies were conducted studying work in process inventory (Conway, 1988).

In an effort to better explain the nature of serial production lines, John D.C. Little (1992) proposed "Little's Law", which was based on queuing theory:

$$L = \lambda W \tag{1}$$

where

- L = the average number of items present in the system
- λ = the average arrival rate, items per unit of time
- W = the average time spent by an item in the system.

This relationship proved to be valid under a wide range of conditions. The notation of Little's Law was changed by Hopp and Spearman (2001) and used as a basis for Factory Physics:

$$WIP = TH \times CT \tag{2}$$

where

- WIP = Work in process inventory
- TH = Throughput of the process, items per unit of time
- CT = Average cycle time, from the start of the process to its end.

The minimum level of WIP can be determined using the fastest possible throughput (the bottleneck rate) and the fastest possible cycle time. The bottleneck rate, r_b, is the rate of the workstation that limits the throughput of the process. The raw process time, T_0, is the sum of the individual unit operation times; it does not include time that materials spend waiting to be processed. The Critical WIP, W_0, is the inventory of a perfect process, operating at the bottleneck rate and the raw process time. This is a theoretically perfect process (Hopp & Spearman, 2001):

$$W_0 = r_b T_0 \tag{3}$$

Any time delays, such as waiting to begin the next step in the process, will increase the cycle time to beyond T_0, and will increase WIP to beyond W_0. Companies that operate with short cycle times, such as many consumer product companies, will experience relatively small levels of WIP. Companies that operate with long cycle times, such as prescription drugs, will operate with much larger levels of WIP. Often, the differences in cycle times are driven not by the nature of the process, but rather by how companies choose to manage their operations.

Internal Benchmarking. Factory Physics' Best-Case Performance Law (Hopp & Spearman, 2001) identifies the minimum cycle time and the maximum throughput for a given WIP level (w) as:

$$\begin{aligned} CT_{best} &= T_0 \quad \text{if } w \le W_0 \\ &= w/r_b \quad \text{otherwise} \end{aligned} \tag{4}$$

$$\begin{aligned} TH_{best} &= w/T_0 \quad \text{if } w \le W_0 \\ &= r_b \quad \text{otherwise} \end{aligned} \tag{5}$$

The worst case performance for a given inventory level (w) is defined by:

$$CT_{worst} = wT_0 \tag{6}$$

$$TH_{worst} = 1/T_0 \tag{7}$$

This represents the highest cycle time and the smallest throughput for a process having a raw process time of T_0.

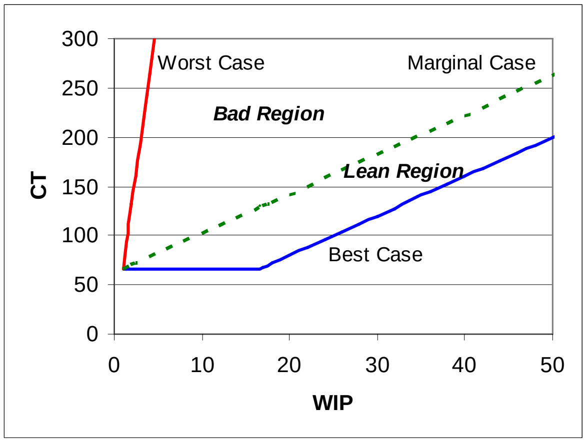
No process will operate at either the best case or the worst case levels, but rather will usually operate somewhere between. It is helpful to have an idea of what might be considered "good". The following represents what the authors call the practical worst case or the marginal case (Absolute Benchmarking, 2004).

$$CT_{PWC} = T_0 + \frac{w-1}{r_b} \tag{8}$$

$$TH_{PWC} = \frac{w}{W_0 + w - 1} r_b \tag{9}$$

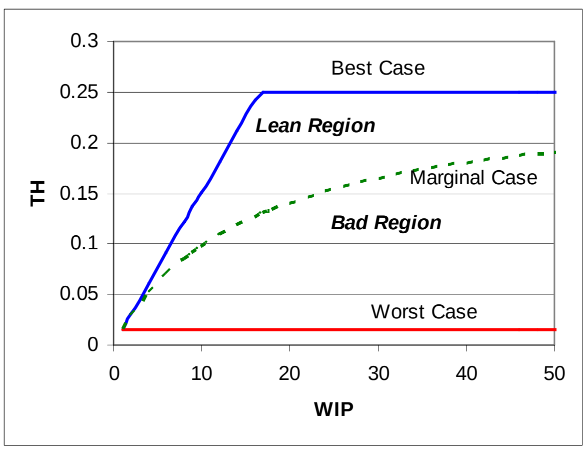
The marginal case determines the division that distinguishes good performance from bad, or lean performance from poor. Best case, worst case, and marginal case performance can be shown graphically. The relationship between work in process and cycle time is shown in Exhibit 1. The space between the marginal line and the best case line is the good region, and can be considered the area of lean manufacturing. The space between the worst case line and the practical worst case line is considered the bad region, and is not where a factory wants to be operating.

Exhibit 1. Cycle Time and Work in Process.



The relationship of work in process and throughput is shown in Exhibit 2. The area above the practical worst case curve is considered good, or the lean region. Operation below the marginal case line is considered inefficient.

Exhibit 2. Throughput and Work in Process.



Nearly any sequential process can be mapped using these graphical tools. The math is applicable to an assembly operation or a chemical process. Companies that focus on lean manufacturing principles are aware of these relationships, and strive to minimize work in process and cycle times in order to maximize their manufacturing efficiencies.

These tools and relationships are used for individual process, assembly, and packaging operations. While the tools are widely applicable, the individual variables are specific to a given operation. They are meant to be used on a micro scale.

Method

Financial Information. In the past few years, companies have been reporting more detailed information in their annual financial statements. Overall inventories have historically been given, but many companies are now reporting results that include raw materials, work in process, and finished product inventories. This added information provides additional insight into a firm's operations. The fact that this new information is available to the public spawned a question. If lean manufacturing tools like internal benchmarking can be used to gauge the efficiency of an individual operation, can the same tools be used to gauge the efficiency of a company as a whole? Annual financial information considers the firm as a whole. The reported data is a composite of the entire company, and only grand averages can be considered. Also, it must be remembered that the reported inventories represent a snapshot in time. Nevertheless, it was felt that if a firm widely practiced lean manufacturing principles, the results should show as an improvement relative to firms that did not practice lean manufacturing.

Annual financial information was gathered from publicly available data. Sources included annual reports available on the internet, public listings and reports from brokerage firms, and internet search engines. The following industries were investigated:

- Automobile industry
- Consumer household products
- U.S. Pharmaceutical industry
  - Prescription drug firms ("Big Pharma")
  - Generic drug firms

Information was collected for fiscal years ending in 2003, 2004, and 2005 where available. The following information was gathered:

- Sales (Revenue)
- Cost of goods sold (COGS)
- Total inventory
- Raw materials
- Work in Process (WIP)
- Finished goods

The above data was assembled and standard financial ratios were determined. Graphs similar to the internal benchmarking graphs shown in Exhibits 1 and 2 were also made.

Cycle Time. An important variable for any manufacturing process is the system's cycle time. The amount of time to process a raw material into a finished product ready for shipping has a profound impact on the operation's WIP. Consider how long it takes Procter & Gamble to make a bottle of liquid detergent from its individual components. Chemicals can be mixed and packaged and put in the warehouse in a mater of a few hours. Very little time or WIP is involved. When P&G started NyQuil Liquicaps, the process cycle time to make unpackaged bulk capsules was six weeks. The resulting work in process was much greater than the company was used to dealing with.

How does one translate an individual cycle time to a corporate average? Most companies have a wide range of products, each having its own unique process and cycle time average. While a relationship may yet be found, this has not been explored. From an initial perspective, cycle time cannot be expanded to a corporate average and still make sense.

Throughput. The throughput of a process is the amount of product made per unit of time. This can be tons per hour, cases per day, or any unit of measure that the firm wants to use. In terms of corporate averages, the throughput of the firm is its sales, or revenue. However, the firm's sales are in terms of sales dollars, not cost dollars; sales figures include profit. If we want to compare inventory and throughput on a common basis, then cost of goods sold is a better measure of throughput. That is why the financial ratio for inventory turnover uses cost of goods sold, not sales (Penman, 2004).

Inventory. Total inventory is widely reported in annual financial reports. In the past few years, many companies (but certainly not all) have begun reporting raw material, work in process, and finished product inventories separately. Some firms, notably those in the automotive industry, report raw material and work in process combined.

Sufficient information exists to do comparisons of various firms. The relationship between the cost of goods sold and work in process inventory can be investigated. What cannot be done is determine a precise region for lean manufacturing. The equations used for determining the lean region apply to specific processes. These cannot be averaged to apply to a corporate result.

A company that has a high throughput will tend to have a high work in process inventory. However, a lower WIP for a given level of throughput will identify a company as being more efficient. So while the relationship between throughput and work in process is valid, the resulting graph cannot be used to determine whether a company qualifies as being "lean". Companies can be compared to each other, however.

Results

Automobiles. Lean manufacturing began in the automobile industry and has been widely embraced. Just in Time (kanban) systems are in use throughout the business. The companies investigated include Daimler Chrysler, Toyota, Honda, Nissan, and Volkswagen. General Motors and Ford do not report WIP inventories.

Data from these companies is shown in Exhibit 3 and plotted in Exhibit 4. If the data represented total inventory instead of work in process inventory, the widely used financial ratio Inventory Turnover could be used, which is defined as (Fraser & Ormiston, 2007):

$$\text{Inventory Turnover} = \text{COGS} / \text{Inventory} \quad (10)$$
(in turns per year)

The data suggests a similar pattern, so a lesser known ratio is used, WIP Turnover, defined as:

$$\text{WIP Turnover} = \text{COGS} / \text{WIP Inventory} \quad (11)$$
(in turns per year)

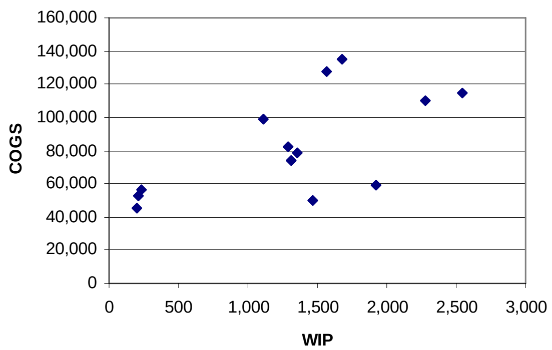
Exhibit 3. Financial data for the Automotive Industry.

(In millions of dollars)

Company	Year	COGS	WIP	WIP Turnover
Toyota	2003	99,120	1,110	89.3
	2004	127,792	1,567	81.6
	2005	135,025	1,676	80.6
Daimler Chrysler	2003	109,926	2,280	48.2
	2004	114,567	2,545	45.0
Honda	2330	45,010	197	228.5
	2004	53,078	210	252.8
	2005	56,227	233	241.3
Nissan	2003	50,096	1,471	34.1
	2004	59,358	1,926	30.8
Volkswagen	2003	74,099	1,308	56.7
	2004	82,391	1,289	63.9
	2005	78,430	1,355	57.9

Since WIP should be minimized, a high WIP Turnover number is preferable. Companies that have a higher WIP Turnover can be seen as having less WIP relative to their throughput, and are operating under more lean conditions. An example is Toyota, which has the two highest values for Cost of Goods sold in Exhibit 4. Toyota has an average WIP Turnover ratio of 84 during the 2003 - 2005 period. Honda, which has the smallest WIP, also has the highest WIP Turnover ratio at 241. Nissan has the lowest ratio at 32.

Exhibit 4. COGS and WIP for the Automotive Industry.



There appears to be a linear relationship among these companies. A regression line was determined, but the results were fairly weak, with $r = 0.63$ and $r^2 = 0.40$. Additional data will be needed to determine if a correlation exists between these variables within the industry.

Consumer Products. Another industry that started adopting lean manufacturing practices many years ago is household consumer products. Corporate information is shown in Exhibit 5 and plotted in Exhibit 6. A strong linear correlation exists; the regression line is shown, with $r = 0.99$ and $r^2 = 0.98$. Procter & Gamble, the largest of the companies shown, has an average WIP Turnover of 76, roughly in line with the best of the automobile companies. Although the cost of goods for individual items is far less in this industry than in automobiles, the sheer volume makes this a category where inventories must be closely managed. The consumer products industry appears to be doing well, if automobiles are a benchmark.

Prescription Drugs. The pharmaceutical business is known to focus on research and the quest for new drug products. Manufacturing is not a focus area for the big pharmaceutical companies (Woodcock, 2001). Exhibit 8 displays data from Pfizer, Johnson & Johnson, Bristol Myers Squibb, Lilly, Abbott, and Schering-Plough. Unlike the consumer products companies, we see a wide diversity of results. In Exhibit 8, the most 'lean' companies will have results toward the upper left corner. Abbott, Johnson & Johnson, and Bristol Myers Squibb appear to have the best results. It should be noted that among this group, Johnson & Johnson is probably the least typical pharmaceutical company; they have substantial over the counter and medical devise businesses. Pfizer is the largest traditional prescription drug company, and has some of the poorest results of the group with an average WIP turnover of 3.5, compared to Abbott's average of 15.4. Clearly, this industry is operating with far higher work in process inventories than the automobile or consumer products industries. In part, this is due to the highly regulated nature of the industry.

Exhibit 5. Financial Data for the Household Products Industry.

(In millions of dollars)

Company	Year	COGS	WIP	WIP Turnover
Procter & Gamble	2003	22,141	291	76.1
	2004	25,076	340	73.8
	2005	27,804	350	79.4
Colgate	2003	4,456	30.4	146.6
	2004	4,747	37.3	127.3
	2005	5,192	37.5	138.5
Pepsico	2003	12,379	160	77.4
	2004	13,406	156	85.9
	2005	14,176	112	126.6
Clorox	2003	2,171	9	241.2
	2004	2,331	3	777.0
	2005	2,493	6	415.5
Estee Lauder	2003	1,324	34	38.9
	2004	1,476	37	39.9
Revlon	2003	501	12	41.8
	2004	485	12	40.4
	2005	508	18	28.2

Exhibit 6. COGS and WIP for the household products industry.

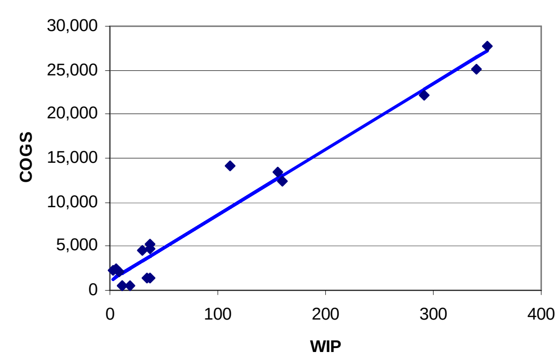
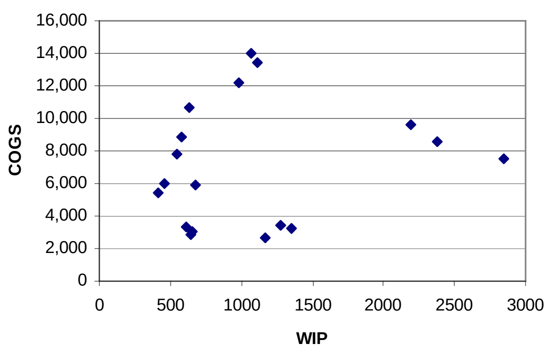


Exhibit 7. Financial Data for the Pharmaceutical Industry.

(In millions of dollars)

Company	Year	COGS	WIP	WIP Turnover
Johnson and Johnson	2003	12,176	981	12.4
	2004	13,422	1113	12.1
	2005	13,954	1073	13.0
Pfizer	2003	9,589	2,198	4.4
	2004	7,541	2,850	2.6
	2005	8,525	2,379	3.6
Bristol Myers Squibb	2003	5,406	416	13.0
	2004	5,989	458	13.1
	2005	5,928	679	8.7
Lilly	2003	2,675	1,169	2.3
	2004	3,224	1,356	2.4
	2005	3,474	1,272	2.7
Abbott	2003	7,774	546	14.2
	2004	8,884	583	15.2
	2005	10,641	630	16.9
Schering Plough	2003	2,833	648	4.4
	2004	3,070	651	4.7
	2005	3,346	614	5.4

Exhibit 8. COGS and WIP for the Pharmaceutical Industry.



Generic Drugs. The generic drug industry represents a different part of the pharmaceutical business. Generic companies have much of their business in the field of prescription drugs that have gone off-patent. The research focus is much less, the competition is more intense, and the impact of manufacturing cost is much greater in the generic companies. The regulatory nature and the manufacturing processes are quite similar to "Big Pharma". A key difference is that the large companies are focused on research while the generic companies are focused on manufacturing.

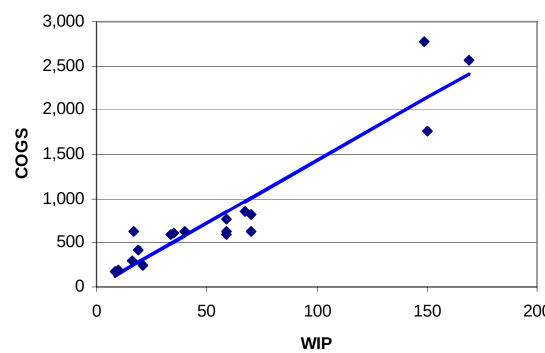
Exhibit 9 shows the financial data for 2003 – 2005. The linear relationship seen in Exhibit 10 is again present, with an r of 0.94 and r^2 of 0.88, implying a common relationship between COGS and WIP among the companies shown. TEVA is the largest of the companies shown, with an average WIP turnover of 15.1, equivalent to the best of the 'Big Pharma' companies. The highest average WIP turnover value was Barr Laboratories with 26.2. The WIP turnover results for the generic companies are higher than the Big Pharma companies, implying a heightened concern for manufacturing and a more "Lean" manufacturing style.

Exhibit 9. Financial Data for the Generic Drug Industry.

(In millions of dollars)

Company	Year	COGS	WIP	WIP Turnover
Watson	2003	625	70.4	8.9
	2004	821	70.2	11.7
	2005	852	67.2	12.7
Teva	2003	1,758	150	11.7
	2004	2,560	169	15.1
	2005	2,770	149	18.6
Mylan	2003	598	34	17.6
	2004	612	35	17.5
	2005	630	40	15.8
Barr Laboratories	2003	424	19	22.3
	2004	633	17	37.2
	2005	304	16	19.0
Elan	2003	250	21.3	11.7
	2004	174	8.2	21.2
	2005	192	9.7	19.8
Perrigo	2003	596	59	10.1
	2004	630	59	10.7
	2005	764	59	12.9

Exhibit 10. COGS and WIP for the Generic Drug Industry.



Conclusions & Recommendations

This initial work has identified that there are definite relationships between work in process inventory and the cost of goods sold within specific industries. The relationship can be seen at the corporate level within the finances of the firm. Industries that tend to embrace lean manufacturing concepts, such as the automotive industry and the household consumer products companies tend to have a high WIP turnover. The Pharmaceutical industry, where manufacturing efficiencies are not a focus, have very low WIP turnovers. Generic drug companies, which comprise a subset of the pharmaceutical industry, have significantly higher WIP turnovers than the big pharmaceutical firms. The focus – or lack of focus – on manufacturing efficiency is reflected in the firm's annual accounting statements.

Further work includes expanding the current database and looking at additional industries. One industry of particular interest is consumer electronics, where Dell built a business model on fast cycle times and low inventories of custom built computers.

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